Fairfield Public Schools
Science Curriculum

AP Physics 2

AP Physics 2: Description

AP Physics 2 is an algebra-based, introductory college-level physics course. Students cultivate their understanding of Physics through inquiry-based investigations as they explore these topics: fluids; thermodynamics; electrical force, field, and potential; electric circuits; magnetism and electromagnetic induction; geometric and physical optics; and quantum, atomic, and nuclear physics. AP Physics 2 is a full year course that is the equivalent of a second semester introductory college course in algebra-based physics.

Standards for this course are taken from the *College Board Advanced Placement Physics 2 course description* and are of three types:
Science Practices: The science practices enable students to establish lines of evidence and use them to develop and refine testable explanations and predictions of natural phenomena.

Big Ideas: The key concepts and related content that define the revised AP Biology course and exam are organized around a few underlying principles called the big ideas, which encompass the core scientific principles, theories and processes governing living organisms and biological systems.

Learning Objectives: Learning objectives provide clear and detailed articulation of what students should know and be able to do. Each learning objective is designed to help teachers integrate science practices with specific content, and to provide them with clear information about how students will be expected to demonstrate their knowledge and abilities.

AP Physics 2: Overview

Enduring Understandings

- The internal structure of a system determines many properties of the system.
- Electric charge is a property of an object or system that effects its interactions with other objects or systems containing charge.
- Objects and systems have properties of inertial mass and gravitational mass that are experimentally verified to be the same and that satisfy conservation principles.
- Classical mechanics cannot describe all properties of objects.
- Materials have many macroscopic properties that result from arrangement and interactions of the atoms and molecules that make up the material.
- A field associates a value of some physical quantity with every point in space. Field models are useful for describing interactions that occur at a distance (long-range forces) as well as a variety of other physical phenomena.
- A gravitational field is caused by an object with mass.
- An electric field is caused by an object with electric charge.
- A magnetic field is caused by a magnet or a moving electrically charged object. Magnetic fields observed in nature always seem to be produced either by moving charged objects or by magnetic dipoles or combinations of dipoles or combinations of dipoles and never by single poles.
- Physicists often construct a map of isolines connecting points of equal value for some quantity related to a field and use these maps to help visualize the field.
- All forces share certain common characteristics when considered by observers in inertial reference frame.
- Classically, the acceleration of an object interacting with other objects can be predicted by using $a=F/m$.
- At the macroscopic level, forces can be categorized as either long-range (action at-a-distance) forces or contact forces.
- A force exerted on an object can change the momentum of the object.
- A force exerted on an object can change the kinetic energy of the object.
- A force exerted on an object can cause a torque on that object.
- Certain types of forces are considered fundamental.
- The acceleration of the center of mass of a system is related to the net force exerted on the system, where $a=F/m$.
- Interactions with other objects or systems can change the total linear momentum of a system.
- Interactions with other objects or systems can change the total energy of a system.
- A net torque exerted on a system by other objects or systems will change the angular momentum of the system.
- The electric and magnetic properties of a system can change in response to the presence of, or changes in, other objects or systems.

- Certain quantities are conserved, in the sense that the changes of those quantities in a given system are always equal to the transfer of that quantity to or from the system by all possible interactions with other systems.
- The energy of a system is conserved.
- The electric charge of a system is conserved.
- The linear momentum of a system is conserved.
- The angular momentum of a system is conserved.
- Classically, the mass of a system is conserved. (Not in AP Physics 1 nucleons conservation)
- A wave is a traveling disturbance that transfers energy and momentum.
- A periodic wave is one that repeats as a function of both time and position and can be described by its amplitude, frequency, wavelength, speed, and energy.
- Only waves exhibit interference and diffraction.
- Interference and superposition lead to standing waves and beats.
- The direction of propagation of a wave such as light may be changed when the wave encounters an interface between two media.
- Electromagnetic radiation can be modeled as waves or as fundamental particles.
- All matter can be modeled as waves or as particles.
- The properties of an ideal gas can be explained in terms of a small number of macroscopic variables including temperature and pressure.
- The tendency of isolated systems to move toward states with higher disorder is describe by probability.
- At the quantum scale, matter is described by a wave function, which leads to a probabilistic description of the microscopic world.

Course Essential Questions

- What are the properties of mass and charge? What internal structures do systems have?
- How can fields existing in space be used to explain interactions?
- What are forces? How can they describe the interactions between or among objects?
- How do interactions between systems change those systems?
- How are changes that occur as a result of interactions explained by conservation laws? What are the constraints of those changes?
- What are waves? How do they transfer energy and momentum from one location to another without the permanent transfer of mass? How can waves serve as a mathematical model for the description of other phenomena?
- How can probabilities be used to describe the behavior of complex systems and interpret the behavior of quantum mechanical systems?

AP Physics 2: Year-at-a Glance

Unit	Title	Unit Essential Questions
1	Fluid Mechanics	• What is the buoyancy force and how does it act on objects in various liquids? • How can we apply Bernoulli's equation describe the conservation of energy in fluid flow? • How can we apply the continuity equation to describe conservation of mass in fluid flow? • What classical laws and principles define the behavior of fluids?
2	Thermodynamics	• How does the internal structure of systems affect their properties? • What is thermal conductivity and how does it relate to energy transfer? • How is energy transferred by thermal processes? • How does the first law of thermodynamics relate to conservation of energy? • How does the pressure of a system relate to changes in momentum of the particles contained in that system? • How does probability describe the thermal equilibrium process? How does it describe the second law of thermodynamics?
3	Electricity & Electric Circuits	• How is electric charge conserved? • What causes an electric field and how does it affect the electric force exerted on an object at various points in space? • How does the electric field change between charged objects and charged plates? • What are isolines and what are they used to represent? • How do Kirchhoff's Laws represent conservation of energy and charge in a circuit? • How do capacitors affect a circuit?
4	Magnetism	• What causes a magnetic field? • What objects are affected by a magnetic field? • What is a magnetic dipole? • What is a ferromagnetic material? • How does changing magnetic flux create an electric field?
5	Waves, Electromagnetic	• How can electromagnetic radiation be modeled as a wave?

	Radiation and Optics	● How does electromagnetic radiation transfer energy? ● How do waves interact with each other? ● How is electromagnetic radiation related to photons? ● How do scientists determine whether to model light as a particle or as a wave? ● How do scientists determine whether to model matter as a particle or as a wave? ● How can matter be modeled by a wave function? How does that function describe its motion and interactions?
6	Modern & Nuclear Physics	● What forces exist inside an atom? ● What evidence is there for Einstein's Theory of Special Relativity? Theory of General Relativity? ● Under what circumstances can mass be converted to energy? Energy to mass? ● Under what circumstances do space and time become not absolute? ● What is nuclear radiation? What different forms exist? ● How does nuclear radiation follow the Law of Conservation of Charge? Law of Conservation of Energy? Law of Conservation of Nucleon Number?

AP Science Practices

Science Practice 1: The student can use representations and models to communicate scientific phenomena and solve scientific problems.
1.1 The student can create representations and models of natural or manmade phenomena and systems in the domain.
1.2 The student can describe representations and models of natural or manmade phenomena and systems in the domain.
1.3 The student can refine representations and models of natural or manmade phenomena and systems in the domain.
1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively.
1.5 The student can re-express key elements of natural phenomena across multiple representations in the domain.
Science Practice 2: The student can use mathematics appropriately
2.1 The student can justify the selection of a mathematical routine to solve problems.
2.2 The student can apply mathematical routines to quantities that describe natural phenomena.
2.3 The student can estimate numerically quantities that describe natural phenomena.
Science Practice 3: The student can engage in scientific questioning to extend thinking or to guide investigations within the context of the AP course.
3.1 The student can pose scientific questions.
3.2 The student can refine scientific questions.
3.3 The student can evaluate scientific questions.
Science Practice 4: The student can plan and implement data collection strategies appropriate to a particular scientific question.
4.1 The student can justify the selection of the kind of data needed to answer a particular scientific question.
4.2 The student can design a plan for collecting data to answer a particular scientific question.
4.3 The student can collect data to answer a particular scientific question.
4.4 The student can evaluate sources of data to answer a particular scientific question
Science Practice 5: The student can perform data analysis and evaluation of evidence.
5.1 The student can analyze data to identify patterns or relationships.
5.2 The student can refine observations and measurements based on data analysis.
5.3 The student can evaluate the evidence provided by data sets in relation to a particular scientific question.
Science Practice 6: The student can work with scientific explanations and theories.
6.1 The student can justify claims with evidence.
6.2 The student can construct explanations of phenomena based on evidence produced through scientific practices.
6.3 The student can articulate the reasons that scientific explanations and theories are refined or replaced.
6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models.
6.5 The student can evaluate alternative scientific explanations.
Science Practice 7: The student is able to connect and relate knowledge across various scales, concepts and representations in and across domains.
7.1 The student can connect phenomena and models across spatial and temporal scales.
7.2 The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.

AP Physics 1: Big Ideas

Big Idea 1: Objects and systems have properties such as mass and charge. Systems may have internal structure.

Big Idea 2: Fields existing in space can be used to explain interactions.

Big Idea 3: The interactions of an object with other objects can be described by forces.

Big Idea 4: Interactions between systems can result in changes in those systems.

Big Idea 5: Changes that occur as a result of interactions are constrained by conservation laws.

Big Idea 6: Waves can transfer energy and momentum from one location to another without the permanent transfer of mass and serve as a mathematical model for the description of other phenomena.

Big Idea 7: The mathematics of probability can be used to describe the behavior of complex systems and to interpret the behavior of quantum mechanical systems.

Unit 1: Fluid Mechanics

Overview

The unit provides a basic algebraic overview of the behavior of non-compressible Newtonian fluids. The unit covers static fluid behavior including buoyancy force calculations as well as hydraulics. It then moves on to dynamic fluid flow centered around the use of Bernoulli's equation as a representation of the conservation of energy of the fluid system.

Performance Expectations

At the conclusion of this unit, students will be able to evaluate why:

- Systems have properties determined by the properties and interactions of their constituent atomic and molecular substructures.
- Matter has a property called density.
- Forces are described by vectors.
- A force exerted on an object is always due to the interaction of that object with another object.
- If one object exerts a force on a second object, the second object always exerts a force of equal magnitude on the first object in the opposite direction.
- If an object of interest interacts with several other objects, the net force is the vector sum of the individual forces.
- Free-body diagrams are useful tools for visualizing forces being exerted on a single object and writing the equations that represent a physical situation.
- Contact forces result from one object touching another object and they arise from interatomic electric forces. These forces include tension, friction, normal, and buoyant.
- Bernoulli's equation describes the conservation of energy in fluid flow. The absolute pressure (P) equals the atmospheric pressure P_0) plus the gauge pressure (pgh).
- The continuity equation describes conservation of mas flow rate in fluids.

Unit Essential Question

- What is the buoyancy force and how does it act on objects in various liquids?
- How can we apply Bernoulli's equation describe the conservation of energy in fluid flow?
- How can we apply the continuity equation to describe conservation of mass in fluid flow?
- What classical laws and principles define the behavior of fluids?

College Board Unit Standards
LO 1.A.2.1: The student is able to construct representations of the differences between a fundamental particle and a system composed of fundamental particles and to relate this to the properties and scales of the systems being investigated. [SP 1.1, 7.1] **LO 1.E.1.1:** The student is able to predict the densities, differences in densities, or changes in densities under different conditions for natural phenomena and design an investigation to verify the prediction. [SP 4.2, 6.4] **LO 1.E.1.2:** The student is able to select from experimental data the information necessary to determine the density of an object and/or compare densities of several objects. [SP 4.1, 6.4] **LO 3.C.4.1:** The student is able to make claims about various contact forces between objects based on the microscopic cause of those forces. [SP 6.1] **LO 3.C.4.2**: The student is able to explain contact forces (tension, friction, normal, buoyant, spring) as arising from interatomic electric forces and that they therefore have certain directions. [SP 6.2] **LO 5.B.10.1:** The student is able to use Bernoulli’s equation to make calculations related to a moving fluid. [SP 2.2] **LO 5.B.10.2:** The student is able to use Bernoulli’s equation and/or the relationship between force and pressure to make calculations related to a moving fluid. [SP 2.2] **LO 5.B.10.3**: The student is able to use Bernoulli’s equation and the continuity equation to make calculations related to a moving fluid. [SP 2.2] **LO 5.B.10.4:** The student is able to construct an explanation of Bernoulli’s equation in terms of the conservation of energy. [SP 6.2] **LO 5.F.1.1**: The student is able to make calculations of quantities related to flow of a fluid, using mass conservation principles (the continuity equation). [SP 2.1, 2.2, 7.2]

Unit 2: Thermodynamics

Overview

This unit covers the Laws of Thermodynamics and Kinetic Theory of Gases. Instruction is centered around the Conservation of Energy (1st Law of Thermodynamics). Covered topics include PV Diagrams, heat flow/energy transfer and work done on and by systems.

Performance Expectations

At the conclusion of this unit, students will be able to evaluate why:

- Systems have properties determined by the properties and interactions of their constituent atomic and molecular substructures.
- Matter has a property called thermal conductivity. Thermal conductivity is the measure of a material's ability to transfer thermal energy.
- Forces are described by vectors
- A force exerted on an object is always due to the interaction of that object with another object.
- If one object exerts a force on a second object, the second object always exerts a force of equal magnitude on the first object in the opposite direction.
- If an object of interest interacts with several other objects, the net force is the vector sum of the individual forces.
- Free-body diagrams are useful tools for visualizing forces being exerted on a single object and writing the equations that represent a physical situation.
- Contact forces result from the interaction of one object touching another object, and they arise from interatomic electric forces. These forces include tension, friction, normal, and buoyant (Physics 2).
- Energy is transferred spontaneously from a higher temperature to a lower temperature system. The process through which energy is transferred between systems at different temperatures is called heat.
- A system with internal structure can have internal energy, and changes in a system's internal structure can result in changes in internal energy. (Physics 2: includes charged object in electric fields and examining changes in configuration)
- The internal energy of a system includes the kinetic energy of the objects that make up the system and the potential energy of the configuration of the objects that make up the system.
- Energy can be transferred by an external force exerted on an object or system that moves the object or system through a distance; this energy transfer is called work. Energy transfer in mechanical or electrical systems may occur at different rates. Power is defined as the rate of energy transfer into, out of, or within a system. The work done on a system is defined as $W=-P\Delta V$ for constant pressure or an average pressure.
- Energy can be transferred by thermal processes involving differences in temperature; this process of transfer is called heat.
- The first law of thermodynamics is a specific case of the law of conservation of energy involving the internal energy of a system and the possible transfer of energy through work and/or heat.
- In a collision between objects, linear momentum is conserved. In an elastic collision, kinetic energy is the same before and after.
- In a collision between objects, linear momentum is conserved. In an inelastic collision, kinetic energy is not the same before and after the

collision.

- The pressure of a system determines the force that the system exerts on the walls of its container and is a measure of the average change in the momentum or impulse of the molecules colliding with the walls of the container. The pressure also exists inside the system itself, not just at the walls of the container.
- The temperature of a system characterizes the average kinetic energy of its molecules.
- In an ideal gas, the macroscopic (average) pressure (P), temperature (T), and volume (V), are related by the ideal gas law PV=nRT.
- The approach to thermal equilibrium is a probability process.
- The second law of thermodynamics describes the change in entropy for reversible and irreversible processes. Only a quantitative treatment is considered in this course.

Unit Essential Questions

- How does the internal structure of systems affect their properties?
- What is thermal conductivity and how does it relate to energy transfer?
- How is energy transferred by thermal processes?
- How does the first law of thermodynamics relate to conservation of energy?
- How does the pressure of a system relate to changes in momentum of the particles contained in that system?
- How does probability describe the thermal equilibrium process? How does it describe the second law of thermodynamics?

College Board Unit Standards

LO 1.E.3.1: The student is able to design an experiment and analyze data from it to examine thermal conductivity. [SP 4.1, 4.2, 5.1]
LO 4.C.3.1: The student is able to make predictions about the direction of energy transfer due to temperature differences based on interactions at the microscopic level. [SP 6.4]
LO 5.A.2.1: The student is able to define open and closed systems for everyday situations and apply conservation concepts for energy, charge, and linear momentum to those situations. [SP 6.4, 7.2]
LO 5.B.4.1: The student is able to describe and make predictions about the internal energy of systems. [SP 6.4, 7.2]
LO 5.B.4.2: The student is able to calculate changes in kinetic energy and potential energy of a system, using information from representations of that system. [SP 1.4, 2.1, 2.2]
LO 5.B.5.4: The student is able to make claims about the interaction between a system and its environment in which the environment exerts a force on the system, thus doing work on the system and changing the energy of the system (kinetic energy plus potential energy). [SP 6.4, 7.2]
LO 5.B.5.5: The student is able to predict and calculate the energy transfer to (i.e., the work done on) an object or system from information about a force exerted on the object or system through a distance. [SP 2.2, 6.4]
LO 5.B.5.6: The student is able to design an experiment and analyze graphical data in which interpretations of the area under a pressure-volume curve are needed to determine the work done on or by the object or system. [SP 4.2, 5.1]
LO 5.B.6.1: The student is able to describe the models that represent processes by which energy can be transferred between a system and its

environment because of differences in temperature: conduction, convection, and radiation. [SP 1.2]
LO 5.B.7.1: The student is able to predict qualitative changes in the internal energy of a thermodynamic system involving transfer of energy due to heat or work done and justify those predictions in terms of conservation of energy principles. [SP 6.4, 7.2]
LO 5.B.7.2: The student is able to create a plot of pressure versus volume for a thermodynamic process from given data. [SP 1.1]
LO 5.B.7.3: The student is able to use a plot of pressure versus volume for a thermodynamic process to make calculations of internal energy changes, heat, or work, based upon conservation of energy principles (i.e., the first law of thermodynamics). [SP 1.1, 1.4, 2.2]
LO 7.A.1.1: The student is able to make claims about how the pressure of an ideal gas is connected to the force exerted by molecules on the walls of the container, and how changes in pressure affect the thermal equilibrium of the system. [SP 6.4, 7.2]
LO 7.A.1.2: Treating a gas molecule as an object (i.e., ignoring its internal structure), the student is able to analyze qualitatively the collisions with a container wall and determine the cause of pressure, and at thermal equilibrium, to quantitatively calculate the pressure, force, or area for a thermodynamic problem given two of the variables. [SP 1.4, 2.2]
LO 7.A.2.1: The student is able to qualitatively connect the average of all kinetic energies of molecules in a system to the temperature of the system. [SP 7.1]
LO 7.A.2.2: The student is able to connect the statistical distribution of microscopic kinetic energies of molecules to the macroscopic temperature of the system and to relate this to thermodynamic processes. [SP 7.1]
LO 7.A.3.1: The student is able to extrapolate from pressure and temperature or volume and temperature data to make the prediction that there is a temperature at which the pressure or volume extrapolates to zero. [SP 6.4, 7.2]
LO 7.A.3.2: The student is able to design a plan for collecting data to determine the relationships between pressure, volume, and temperature, and amount of an ideal gas, and to refine a scientific question concerning a proposed incorrect relationship between the variables. [SP 3.2, 4.2]
LO 7.A.3.3: The student is able to analyze graphical representations of macroscopic variables for an ideal gas to determine the relationships between these variables and to ultimately determine the ideal gas law $PV = nRT$. [SP 5.1]
LO 7.B.1.1: The student is able to construct an explanation, based on atomic-scale interactions and probability, of how a system approaches [SP 6.4, 7.2]
LO 7.B.2.1: The student is able to connect qualitatively the second law of thermodynamics in terms of the state function called entropy and how it (entropy) behaves in reversible and irreversible processes. [SP 7.1]

Unit 3: Electricity & Electric Circuits

Overview

Electric charge is the fundamental property of an object that determines how the object interacts with other electrically charged objects. The interaction of a charged object with a distribution of other charged objects is simplified by the field model, where a distribution of charged objects creates a field at every point and the charged object interacts with the field. There are two types of electric charge, positive and negative. The course covers static charges, charged plates, and DC and RC circuits. Where capacitors are involved, the course considers the initial and final steady states of the capacitors.

Performance Expectations

At the conclusion of this unit, students will be able to evaluate why:

- Systems have properties determined by the properties and interactions of their constituent atomic and molecular substructures.
- Electric charge is conserved. The net charge of a system is equal to the sum of the charges of all objects in the system.
- There are only two kinds of electric charge. Neutral objects or systems contain equal quantities of positive and negative charge, with the exception of some fundamental particles that have no electric charge.
- The smallest observed unit of charge that can be isolated is the electron charge, also known as the elementary charge.
- Matter has a property called electric permittivity.
- A vector field gives, as a function of position (and perhaps time) the value of a physical quantity that is described by a vector.
- A scalar field gives, as a function of position (and perhaps time) the value of a physical quantity that is described by a scalar. (In Physics 2 this should include electric potential)
- The magnitude of the electric force F exerted on an object with an electric charge q by an electric field E is $F=qE$. The direction of the force is determined by the direction of the field and the sign of the charge, with positively charged objects accelerating in the direction of the field and negatively charged objects accelerating in the direction opposite the field. This should include a vector map for positive point charges, negative point charges, spherically symmetric charge distributions, and uniformly charged parallel plates.
- The magnitude of the electric field vector is proportional to the net electric charge of the object(s) creating that field. This includes positive point charges, spherically symmetric charge distributions and uniformly charged parallel plates.
- The electric field outside a spherically symmetric charged object is radial and its magnitude varies a sthe inverse square of the radial distance from the center of that object.
- The electric field around dipoles and other systems of electrically charged objects (that can be modeled as point objects) is found by vector addition of the field of each individual object.
- Between two oppositely charged parallel plates with uniformly distributed electric charge, at points far from the edges of the plates, the electric field is perpendicular to the plates and is constant in both magnitude and direction.
- Isolines on a topographic (elevation) map describe lines of approximate equal gravitational potential energy per unit mass (gravitational

equipotential). As the distance between the two different isolines decreases, the steepness of the surface increases.

- Isolines in a region where an electric field exists represent lines of equal electric potential, referred to as equipotential lines.
- The average value of the electric field in a region equals the change in electric potential across that region divided by the change in position (displacement) in the relevant direction.
- Forces are described by vectors.
- A force exerted on an object is always due to the interaction of that object with another object.
- If one object exerts a force on a second object, the second object always exerts a force of equal magnitude on the first object in the opposite direction.
- If an object of interest interacts with several other objects, the net force is the vector sum of the individual forces.
- Free-body diagrams are useful tools for visualizing forces being exerted on a single object and writing equations that represent a physical situation.
- Electric force results from the interaction of one object that has an electric charge with another object that has an electric charge.
- Gravitational forces are exerted at all scales and dominate at the largest distance and mass scales.
- Electromagnetic forces are exerted at all scales and can dominate at the human scale.
- The charge distribution in a system can be altered by the effects of electric forces produced by a charged object.
- A system with internal structure can have internal energy and changes in a system's internal structure can result in changes in internal energy. (Physics 2: includes charged object in electric fields and examining changes in internal energy with changes in configuration)
- The internal energy of a system includes the kinetic energy of the objects that make up the system and the potential energy of the configuration of the objects that make up the system.
- Energy cam be transferred by an external force exerted on an object or system that moves the object or system through a distance; this energy transfer is called work. Energy transfer in mechanical or electrical systems may occur at different rates. Power is defined as the rate of energy transfer into, out of, or within a system. The work done on a system is defined as $W=-P\Delta V$ for constant pressure or an average pressure.
- The exchange of electric charges among a set of objects in a system conserves electric charge.
- Matter has a property called resistivity.
- The resistance of a resistor, and the capacitance of a capacitor, can be understood from the basic properties of electric fields and forces, as well as the properties of materials and their geometry.
- The values of currents and electric potential differences in an electric circuit are determined by the properties and arrangement of the individual circuit elements such as sources of emf, resistors, and capacitors.
- Kirchoff's loop rule describes conservation of energy in electrical circuits.
- Kirchoff's junction rule describes the conservation of electric charge in electrical circuits. Since charged is conserved, current must be conserved at each junction in the circuit.

Unit Essential Questions
● How is electric charge conserved? ● What causes an electric field and how does it affect the electric force exerted on an object at various points in space? ● How does the electric field change between charged objects and charged plates? ● What are isolines and what are they used to represent? ● How do Kirchhoff's Laws represent conservation of energy and charge in a circuit? ● How do capacitors affect a circuit?

College Board Unit Standards
LO 1.B.1.1: The student is able to make claims about natural phenomena based on conservation of electric charge. [SP 6.4] **LO 1.B.1.2:** The student is able to make predictions, using the conservation of electric charge, about the sign and relative quantity of net charge of objects or systems after various charging processes, including conservation of charge in simple circuits. [SP 6.4, 7.2] **LO 1.B.2.2:** The student is able to make a qualitative prediction about the distribution of positive and negative electric charges within neutral systems as they undergo various processes. [SP 6.4, 7.2] **LO 1.B.2.3**: The student is able to challenge claims that polarization of electric charge or separation of charge must result in a net charge on the object. [SP6.1] **LO 1.B.3.1:** The student is able to challenge the claim that an electric charge smaller than the elementary charge has been isolated. [SP 1.5, 6.1, 7.2] **LO 2.C.1.1:** The student is able to predict the direction and the magnitude of the force exerted on an object with an electric charge q placed in an electric field E using the mathematical model of the relation between an electric force and an electric field: $\vec{F} = q\vec{E}$; a vector relation.[SP 6.4, 7.2] **LO 2.C.1.2:** The student is able to calculate any one of the variables — electric force, electric charge, and electric field — at a point given the values and sign or direction of the other two quantities.[SP 2.2] **LO 2.C.2.1:** The student is able to qualitatively and semi-quantitatively apply the vector relationship between the electric field and the net electric charge creating that field. [SP 2.2, 6.4] **LO 2.C.3.1:** The student is able to explain the inverse square dependence of the electric field surrounding a spherically symmetric electrically charged object. [SP 6.2] **LO 2.C.4.1:** The student is able to distinguish the characteristics that differ between monopole fields (gravitational field of spherical mass and electrical field due to single point charge) and dipole fields (electric dipole field and magnetic field) and make claims about the spatial behavior of the fields using qualitative or semi-quantitative arguments based on vector addition of fields due to each point source, including identifying the locations and signs of sources from a vector diagram of the field. [SP 2.2, 6.4, 7.2] **LO 2.C.4.2:** The student is able to apply mathematical routines to determine the magnitude and direction of the electric field at specified points in the vicinity of a small set (2–4) of point charges, and express the results in terms of magnitude and direction of the field in a visual representation by drawing field vectors of appropriate length and direction at the specified points. [SP 1.4, 2.2] **LO 2.C.5.1:** The student is able to create representations of the magnitude and direction of the electric field at various distances (small compared to plate size) from two electrically charged plates of equal magnitude and opposite signs, and is able to recognize that the assumption of uniform

field is not appropriate near edges of plates. [SP 1.1, 2.2]
LO 2.C.5.2: The student is able to calculate the magnitude and determine the direction of the electric field between two electrically charged parallel plates, given the charge of each plate, or the electric potential difference and plate separation. [SP 2.2]
LO 2.C.5.3: The student is able to represent the motion of an electrically charged particle in the uniform field between two oppositely charged plates and express the connection of this motion to projectile motion of an object with mass in the Earth's gravitational field. [SP 1.1, 2.2, 7.1]
LO 2.E.1.1: The student is able to construct or interpret visual representations of the isolines of equal gravitational potential energy per unit mass and refer to each line as a gravitational equipotential. [SP 1.4, 6.4, 7.2]
LO 2.E.2.1: The student is able to determine the structure of isolines of electric potential by constructing them in a given electric field. [SP 6.4, 7.2]
LO 2.E.2.2: The student is able to predict the structure of isolines of electric potential by constructing them in a given electric field and make connections between these isolines and those found in a gravitational field. [SP 6.4, 7.2]
LO 2.E.2.3: The student is able to qualitatively use the concept of isolines to construct isolines of electric potential in an electric field and determine the effect of that field on electrically charged objects. [SP 1.4]
LO 2.E.3.1: The student is able to apply mathematical routines to calculate the average value of the magnitude of the electric field in a region from a description of the electric potential in that region using the displacement along the line on which the difference in potential is evaluated. [SP 2.2]
LO 2.E.3.2: The student is able to apply the concept of the isoline representation of electric potential for a given electric charge distribution to predict the average value of the electric field in the region. [SP 1.4, 6.4]
LO 3.A.2.1: The student is able to represent forces in diagrams or mathematically using appropriately labeled vectors with magnitude, direction, and units during the analysis of a situation. [SP 1.1]
LO 3.A.3.2: The student is able to challenge a claim that an object can exert a force on itself. [SP 6.1]
LO 3.A.3.3: The student is able to describe a force as an interaction between two objects and identify both objects for any force. [SP 1.4]
LO 3.A.3.4: The student is able to make claims about the force on an object due to the presence of other objects with the same property: mass, electric charge. [SP 6.1, 6.4]
LO 3.A.4.1: The student is able to construct explanations of physical situations involving the interaction of bodies using Newton's third law and the representation of action-reaction pairs of forces. [SP 1.4, 6.2]
LO 3.A.4.2: The student is able to use Newton's third law to make claims and predictions about the action-reaction pairs of forces when two objects interact. [SP 6.4, 7.2]
LO 3.A.4.3: The student is able to analyze situations involving interactions among several objects by using free-body diagrams that include the application of Newton's third law to identify forces. [SP 1.4]
LO 3.B.1.3: The student is able to re-express a free-body diagram representation into a mathematical representation and solve the mathematical representation for the acceleration of the object. [SP 1.5, 2.2]
LO 3.B.1.4: The student is able to predict the motion of an object subject to forces exerted by several objects using an application of Newton's second law in a variety of physical situations. [SP 6.4, 7.2]
LO 3.B.2.1: The student is able to create and use free-body diagrams to analyze physical situations to solve problems with motion qualitatively and quantitatively. [SP 1.1, 1.4, 2.2]
LO 3.C.2.1: The student is able to use Coulomb's law qualitatively and quantitatively to make predictions about the interaction between two electric point charges. [SP 2.2, 6.4]

LO 3.C.2.2: The student is able to connect the concepts of gravitational force and electric force to compare similarities and differences between the forces. [SP 7.2]
LO 3.C.2.3: The student is able to use mathematics to describe the electric force that results from the interaction of several separated point charges (generally 2 to 4 point charges, though more are permitted in situations of high symmetry). [SP 2.2]
LO 3.G.1.2: The student is able to connect the strength of the gravitational force between two objects to the spatial scale of the situation and the masses of the objects involved and compare that strength to other types of forces. [SP 7.1]
LO 3.G.2.1: The student is able to connect the strength of electromagnetic forces with the spatial scale of the situation, the magnitude of the electric charges, and the motion of the electrically charged objects involved. [SP 7.1]
LO 4.E.3.1: The student is able to make predictions about the redistribution of charge during charging by friction, conduction, and induction. [SP 6.4]
LO 4.E.3.2: The student is able to make predictions about the redistribution of charge caused by the electric field due to other systems, resulting in charged or polarized objects. [SP 6.4, 7.2]
LO 4.E.3.3: The student is able to construct a representation of the distribution of fixed and mobile charge in insulators and conductors. [SP 1.1, 1.4, 6.4]
LO 4.E.3.4: The student is able to construct a representation of the distribution of fixed and mobile charge in insulators and conductors that predicts charge distribution in processes involving induction or conduction. [SP 1.1, 1.4, 6.4]
LO 4.E.3.5: The student is able to plan and/or analyze the results of experiments in which electric charge rearrangement occurs by electrostatic induction, or is able to refine a scientific question relating to such an experiment by identifying anomalies in a data set or procedure. [SP 3.2, 4.1, 4.2, 5.1, 5.3]
LO 5.A.2.1: The student is able to define open and closed systems for everyday situations and apply conservation concepts for energy, charge, and linear momentum to those situations. [SP 6.4, 7.2]
LO 5.B.2.1: The student is able to calculate the expected behavior of a system using the object model (i.e., by ignoring changes in internal structure) to analyze a situation. Then, when the model fails, the student can justify the use of conservation of energy principles to calculate the change in internal energy due to changes in internal structure because the object is actually a system. [SP 1.4, 2.1]
LO 5.C.2.1: The student is able to predict electric charges on objects within a system by application of the principle of charge conservation within a system. [SP 6.4]
LO 5.C.2.2: The student is able to design a plan to collect data on the electrical charging of objects and electric charge induction on neutral objects and qualitatively analyze that data. [SP 4.2, 5.1]
LO 5.C.2.3: The student is able to justify the selection of data relevant to an investigation of the electrical charging of objects and electric charge induction on neutral objects. [SP 4.1]
LO 1.E.2.1: The student is able to choose and justify the selection of data needed to determine resistivity for a given material. [SP 4.1]
LO 4.E.4.1: The student is able to make predictions about the properties of resistors and/or capacitors when placed in a simple circuit, based on the geometry of the circuit element and supported by scientific theories and mathematical relationships. [SP 2.2, 6.4]
LO 4.E.4.2: The student is able to design a plan for the collection of data to determine the effect of changing the geometry and/or materials on the resistance or capacitance of a circuit element and relate results to the basic properties of resistors and capacitors. [SP 4.1, 4.2]
LO 4.E.4.3: The student is able to analyze data to determine the effect of changing the geometry and/or materials on the resistance or capacitance of a circuit element and relate results to the basic properties of resistors and capacitors. [SP 5.1]

LO 4.E.5.1: The student is able to make and justify a quantitative prediction of the effect of a change in values or arrangements of one or two circuit elements on the currents and potential differences in a circuit containing a small number of sources of emf, resistors, capacitors, and switches in series and/or parallel. [SP 2.2, 6.4]
LO 4.E.5.2: The student is able to make and justify a qualitative prediction of the effect of a change in values or arrangements of one or two circuit elements on currents and potential differences in a circuit containing a small number of sources of emf, resistors, capacitors, and switches in series and/or parallel. [SP 6.1, 6.4]
LO 4.E.5.3: The student is able to plan data collection strategies and perform data analysis to examine the values of currents and potential differences in an electric circuit that is modified by changing or rearranging circuit elements, including sources of emf, resistors, and capacitors. [SP 2.2, 4.2, 5.1]
LO 5.B.9.4: The student is able to analyze experimental data including an analysis of experimental uncertainty that will demonstrate the validity of Kirchhoff's loop rule.[SP 5.1]
LO 5.B.9.5: The student is able to use conservation of energy principles (Kirchhoff's loop rule) to describe and make predictions regarding electrical potential difference, charge, and current in steady-state circuits composed of various combinations of resistors and capacitors. [SP 6.4]
LO 5.B.9.6: The student is able to mathematically express the changes in electric potential energy of a loop in a multiloop electrical circuit and justify this expression using the principle of the conservation of energy. [SP 2.1, 2.2]
LO 5.B.9.7: The student is able to refine and analyze a scientific question for an experiment using Kirchhoff's Loop rule for circuits that includes determination of internal resistance of the battery and analysis of a non-ohmic resistor. [SP 4.1, 4.2, 5.1, 5.3]
LO 5.B.9.8: The student is able to translate between graphical and symbolic representations of experimental data describing relationships among power, current, and potential difference across a resistor. [SP 1.5]
LO 5.C.3.4: The student is able to predict or explain current values in series and parallel arrangements of resistors and other branching circuits using Kirchhoff's junction rule and relate the rule to the law of charge conservation. [SP 6.4, 7.2]
LO 5.C.3.5: The student is able to determine missing values and direction of electric current in branches of a circuit with resistors and NO capacitors from values and directions of current in other branches of the circuit through appropriate selection of nodes and application of the junction rule. [SP 1.4, 2.2]
LO 5.C.3.6: The student is able to determine missing values and direction of electric current in branches of a circuit with both resistors and capacitors from values and directions of current in other branches of the circuit through appropriate selection of nodes and application of the junction rule. [SP 1.4, 2.2]
5.C.3.7: The student is able to determine missing values, direction of electric current, charge of capacitors at steady state, and potential differences within a circuit with resistors and capacitors from values and directions of current in other branches of the circuit. [SP 1.4, 2.2]

Unit 4: Magnetism

Overview

Knowledge of the properties and sources of magnetic forces and magnetic fields is necessary to student understanding of areas such as geophysical processes and medical applications. Magnetic materials contain magnetic domains that are themselves little magnets. Representations can be drawn of the atomic-scale structure of ferromagnetic materials, such as arrows or smaller bar magnets, which indicate the directional nature of magnets even at these small scales. These magnetic moments lead to discussions of important modern applications such as magnetic storage media.

Performance Expectations

At the conclusion of this unit, students will be able to evaluate why:

- Systems have properties determined by the properties and interactions of their constituent atomic and molecular substructures.
- Matter has a property called magnetic permeability.
- Matter has a property called magnetic dipole moment.
- A vector field gives, as a function of position (and perhaps time) the value of a physical quantity that is described by a vector.
- A scalar field gives, as a function of position (and perhaps time) the value of a physical quantity that is described by a scalar. (In Physics 2 this should include electric potential)
- The electric field around dipoles and other systems of electrically charged objects (that can be modeled as point objects) is found by vector addition of the field of each individual object.
- The magnetic field exerts a force on a moving electrically charged object. The magnetic force is perpendicular to the direction of the velocity of the object and to the magnetic field and is proportional to the magnitude of the charge, the magnitude of the velocity and the magnitude of the magnetic field. It also depends on the angle between the velocity and the magnetic field vectors.
- The magnetic field vectors around a straight wire that carries electric current are tangent to concentric circles centered on that wire. The field has no component toward the current-carrying wire.
- A magnetic dipole placed in a magnetic field, such as the ones created by a magnet or the Earth, will tend to align with the magnetic field vector.
- Ferromagnetic materials contain magnetic domains that are themselves magnets.
- Forces are described by vectors.
- A force exerted on an object is always due to the interaction of that object with another object.
- If one object exerts a force on a second object, the second object always exerts a force of equal magnitude on the first object in the opposite direction.
- If an object of interest interacts with several other objects, the net force is the vector sum of the individual forces.
- Free-body diagrams are useful tools for visualizing forces being exerted on a single object and writing the equations that represent a

physical situation.

- A magnetic force results from the interaction of a moving charged object or a magnet with other moving charged objects or magnets.
- Electromagnetic forces are exerted at all scales and can dominate at the human scale.
- The magnetic properties of some materials can be affected by magnetic fields at the system.
- Changing magnetic flux induces an electric field that can establish an induced emf in a system.

Unit Essential Questions

- What causes a magnetic field?
- What objects are affected by a magnetic field?
- What is a magnetic dipole?
- What is a ferromagnetic material?
- How does changing magnetic flux create an electric field?

College Board Unit Standards

LO 3.A.2.1: The student is able to represent forces in diagrams or mathematically using appropriately labeled vectors with magnitude, direction, and units during the analysis of a situation. [SP 1.1]
LO 3.A.3.2: The student is able to challenge a claim that an object can exert a force on itself. [SP 6.1]
LO 3.A.3.3: The student is able to describe a force as an interaction between two objects and identify both objects for any force. [SP 1.4]
LO 3.A.4.1: The student is able to construct explanations of physical situations involving the interaction of bodies using Newton's third law and the representation of action-reaction pairs of forces. [SP 1.4, 6.2]
LO 3.A.4.2: The student is able to use Newton's third law to make claims and predictions about the action-reaction pairs of forces when two objects interact. [SP 6.4, 7.2]
LO 3.A.4.3: The student is able to analyze situations involving interactions among several objects by using free-body diagrams that include the application of Newton's third law to identify forces. [SP 1.4]
LO 3.C.3.1: The student is able to use right-hand rules to analyze a situation involving a current-carrying conductor and a moving electrically charged object to determine the direction of the magnetic force exerted on the charged object due to the magnetic field created by the current-carrying conductor. [SP 1.4]
LO 3.C.3.2: The student is able to plan a data collection strategy appropriate to an investigation of the direction of the force on a moving electrically charged object caused by a current in a wire in the context of a specific set of equipment and instruments and analyze the resulting data to arrive at a conclusion. [SP 4.2, 5.1]
LO 4.E.1.1: The student is able to use representations and models to qualitatively describe the magnetic properties of some materials that can be

affected by magnetic properties of other objects in the system. [SP 1.1, 1.4, 2.2]
LO 4.E.2.1: The student is able to construct an explanation of the function of a simple electromagnetic device in which an induced emf is produced by a changing magnetic flux through an area defined by a current loop (i.e., a simple microphone or generator) or of the effect on behavior of a device in which an induced emf is produced by a constant magnetic field through a changing area. [SP 6.4]

Unit 5: Waves, Electromagnetic Radiation & Optics

Overview

This unit covers wave properties but focuses on electromagnetic (EM) radiation. Properties of different wavelengths are discussed as well as how different media affect the EM wave. Geometric optics are covered, including ray diagrams, for transparent media interfaces as well as traditional mirrors. The unit concludes with the discussion of EM waves as photon particles and of traditional matter as waves.

Performance Expectations

At the conclusion of this unit, students will be able to:

- Objects classically thought of as particles can exhibit properties of waves.
- Certain phenomena classically thought of as waves can exhibit properties of particles.
- Energy transfer occurs when photons are absorbed or emitted, for example, by atoms or nuclei.
- Waves can propagate via different oscillation modes such as transverse and longitudinal.
- For propagation, mechanical waves require a medium, while electromagnetic waves do not require a physical medium. Examples should include light traveling through a vacuum and sound not traveling through a vacuum.
- A simple wave can be described by an equation involving one sine or cosine function involving the wavelength, amplitude, and frequency of the wave.
- When two waves cross, they travel through each other; they do not bounce off each other. Where the waves overlap, the resulting displacement can be determined by adding the displacements of the two waves. This is called superposition.
- When waves pass through an opening whose dimensions are comparable to the wavelength, a diffraction pattern can be observed.
- When waves pass through a set of openings whose spacing is comparable to the wavelength, an interference pattern can be observed. Examples should include monochromatic double-slit interference.
- When waves pass by an edge, they can diffract into the “shadow region” behind the edge. Examples should include hearing around corners, but not seeing around them, and water waves bending around obstacles
- When light travels from one medium to another, some of the light is transmitted, some is reflected, and some is absorbed. (Qualitative understanding only.)
- When light hits a smooth reflecting surface at an angle, it reflects at the same angle on the other side of the line perpendicular to the surface (specular reflection); this law of reflection accounts for the size and location of images seen in mirrors.
- When light travels across a boundary from one transparent material to another, the speed of propagation changes. At a non-normal incident angle, the path of the light ray bends closer to the perpendicular in the optically slower substance. This is called refraction.
- The reflection of light from surfaces can be used to form images.
- The refraction of light as it travels from one transparent medium to another can be used to form images.
- Types of electromagnetic radiation are characterized by their wavelengths, and certain ranges of wavelength have been given specific names. These include (in order of increasing wavelength spanning a range from picometers to kilometers) gamma rays, x–rays, ultraviolet,

visible light, infrared, microwaves, and radio waves.

- Electromagnetic waves can transmit energy through a medium and through a vacuum.
- Photons are individual energy packets of electromagnetic waves, with Ephoton = hf, where h is Planck's constant and f is the frequency of the associated light wave.
- The nature of light requires that different models of light are most appropriate at different scales.
- Under certain regimes of energy or distance, matter can be modeled as a classical particle.
- Under certain regimes of energy or distance, matter can be modeled as a wave. The behavior in these regimes is described by quantum mechanics.
- The probabilistic description of matter is modeled by a wave function, which can be assigned to an object and used to describe its motion and interactions. The absolute value of the wave function is related to the probability of finding a particle in some spatial region.
- Photon emission and absorption processes are described by probability.

Unit Essential Questions

- How can electromagnetic radiation be modeled as a wave?
- How does electromagnetic radiation transfer energy?
- How do waves interact with each other?
- How is electromagnetic radiation related to photons?
- How do scientists determine whether to model light as a particle or as a wave?
- How do scientists determine whether to model matter as a particle or as a wave?
- How can matter be modeled by a wave function? How does that function describe its motion and interactions?

College Board Unit Standards

LO 6.A.1.2: The student is able to describe representations of transverse and longitudinal waves. [SP 1.2]
LO 6.A.1.3: The student is able to analyze data (or a visual representation) to identify patterns that indicate that a particular mechanical wave is polarized and construct an explanation of the fact that the wave must have a vibration perpendicular to the direction of energy propagation. [SP 5.1, 6.2]
LO 6.A.2.2: The student is able to contrast mechanical and electromagnetic waves in terms of the need for a medium in wave propagation. [SP 6.4, 7.2]
LO 6.B.3.1: The student is able to construct an equation relating the wavelength and amplitude of a wave from a graphical representation of the electric or magnetic field value as a function of position at a given time instant and vice versa, or construct an equation relating the frequency or period and amplitude of a wave from a graphical representation of the electric or magnetic field value at a given position as a function of time and vice versa. [SP 1.5]
LO 6.C.1.1: The student is able to make claims and predictions about the net disturbance that occurs when two waves overlap. Examples should

include standing waves. [SP 6.4, 7.2]

LO 6.C.1.2: The student is able to construct representations to graphically analyze situations in which two waves overlap over time using the principle of superposition. [SP 1.4]

LO 6.C.2.1: The student is able to make claims about the diffraction pattern produced when a wave passes through a small opening, and to qualitatively apply the wave model to quantities that describe the generation of a diffraction pattern when a wave passes through an opening whose dimensions are comparable to the wavelength of the wave. [SP 1.4, 6.4, 7.2]

LO 6.C.3.1: The student is able to qualitatively apply the wave model to quantities that describe the generation of interference patterns to make predictions about interference patterns that form when waves pass through a set of openings whose spacing and widths are small compared to the wavelength of the waves. [SP 1.4, 6.4]

LO 6.C.4.1: The student is able to predict and explain, using representations and models, the ability or inability of waves to transfer energy around corners and behind obstacles in terms of the diffraction property of waves in situations involving various kinds of wave phenomena, including sound and light. [SP 6.4, 7.2]

LO 6.E.1.1: The student is able to make claims using connections across concepts about the behavior of light as the wave travels from one medium into another, as some is transmitted, some is reflected, and some is absorbed. [SP 6.4, 7.2]

LO 6.E.2.1: The student is able to make predictions about the locations of object and image relative to the location of a reflecting surface. The prediction should be based on the model of specular reflection with all angles measured relative to the normal to the surface. [SP 6.4, 7.2]

LO 6.E.3.1: The student is able to describe models of light traveling across a boundary from one transparent material to another when the speed of propagation changes, causing a change in the path of the light ray at the boundary of the two media. [SP 1.1, 1.4]

LO 6.E.3.2: The student is able to plan data collection strategies as well as perform data analysis and evaluation of the evidence for finding the relationship between the angle of incidence and the angle of refraction for light crossing boundaries from one transparent material to another (Snell's law). [SP 4.1, 5.1, 5.2, 5.3]

LO 6.E.3.3: The student is able to make claims and predictions about path changes for light traveling across a boundary from one transparent material to another at non-normal angles resulting from changes in the speed of propagation. [SP 6.4, 7.2]

LO 6.E.4.1: The student is able to plan data collection strategies, and perform data analysis and evaluation of evidence about the formation of images due to reflection of light from curved spherical mirrors. [SP 3.2, 4.1, 5.1, 5.2, 5.3]

LO 6.E.4.2: The student is able to use quantitative and qualitative representations and models to analyze situations and solve problems about image formation occurring due to the reflection of light from surfaces. [SP 1.4, 2.2]

LO 6.E.5.1: The student is able to use quantitative and qualitative representations and models to analyze situations and solve problems about image formation occurring due to the refraction of light through thin lenses. [SSP 1.4, 2.2]

LO 6.E.5.2: The student is able to plan data collection strategies, perform data analysis and evaluation of evidence, and refine scientific questions about the formation of images due to refraction for thin lenses. [SP 3.2, 4.1, 5.1, 5.2, 5.3]

LO 6.F.1.1: The student is able to make qualitative comparisons of the wavelengths of types of electromagnetic radiation. [SP 6.4, 7.2]

LO 6.F.2.1: The student is able to describe representations and models of electromagnetic waves that explain the transmission of energy when no medium is present. [SP 1.1]

Unit 6: Modern & Nuclear Physics

Overview

The final unit covers nuclear physics involving fission, fusion and radiation. The unit uses the conservation laws previously mentioned in prior units and adds the final conservation law, the Law of Nucleon Number. The unit concludes with a qualitative discussion of Einstein's Special and General Relativity. Students do not need to quantitatively calculate time dilation and length contraction but should be able to qualitatively explain these phenomena and identify scenarios that prove the existence of special relativity.

Performance Expectations

At the conclusion of this unit, students will be able to evaluate why:

- Fundamental particles have no internal structure.
- Nuclei have internal structures that determine their properties.
- Atoms have internal structures that determine their properties.
- Systems have properties determined by the properties and interactions of their constituent atomic and molecular substructures.
- In certain processes, mass can be converted to energy and energy can be converted to mass according to E = mc 2, the equation derived from the theory of special relativity.
- Properties of space and time cannot always be treated as absolute.
- The strong force is exerted at nuclear scales and dominates the interactions of nucleons.
- Mass can be converted into energy, and energy can be converted into mass.
- Beyond the classical approximation, mass is actually part of the internal energy of an object or system with E=mc2.
- Electric charge is conserved in nuclear and elementary particle reactions, even when elementary particles are produced or destroyed.
- The possible nuclear reactions are constrained by the law of conservation of nucleon number.
- The allowed states for an electron in an atom can be calculated from the wave model of an electron.
- The spontaneous radioactive decay of an individual nucleus is described by probability.
- Photon emission and absorption processes are described by probability.

Unit Essential Questions

- What forces exist inside an atom?
- What evidence is there for Einstein's Theory of Special Relativity? Theory of General Relativity?
- Under what circumstances can mass be converted to energy? Energy to mass?
- Under what circumstances do space and time become not absolute?

- What is nuclear radiation? What different forms exist?
- How does nuclear radiation follow the Law of Conservation of Charge? Law of Conservation of Energy? Law of Conservation of Nucleon Number?

College Board Unit Standards

LO 1.A.2.1: The student is able to construct representations of the differences between a fundamental particle and a system composed of fundamental particles and to relate this to the properties and scales of the systems being investigated. [SP 1.1, 7.1]

LO 1.A.4.1: The student is able to construct representations of the energy-level structure of an electron in an atom and to relate this to the properties and scales of the systems being investigated. [SP 1.1, 7.1**]**

LO 1.C.4.1: The student is able to articulate the reasons that the theory of conservation of mass was replaced by the theory of conservation of mass-energy. **[SP 6.3]**

LO 1.D.1.1: The student is able to explain why classical mechanics cannot describe all properties of objects by articulating the reasons that classical mechanics must be refined and an alternative explanation developed when classical particles display wave properties. [SP 6.3]

LO 1.D.3.1: The student is able to articulate the reasons that classical mechanics must be replaced by special relativity to describe the experimental results and theoretical predictions that show that the properties of space and time are not absolute. [SP 6.3, 7.1]

LO 3.G.3.1: The student is able to identify the strong force as the force that is responsible for holding the nucleus together. [SP 7.2]

LO 4.C.4.1: The student is able to apply mathematical routines to describe the relationship between mass and energy and apply this concept across domains of scale. [SP 2.2, 2.3, 7.2]

LO 5.B.8.1: The student is able to describe emission or absorption spectra associated with electronic or nuclear transitions as transitions between allowed energy states of the atom in terms of the principle of energy conservation, including characterization of the frequency of radiation emitted or absorbed. [SP 1.2, 7.2]

LO 5.B.11.1: The student is able to apply conservation of mass and conservation of energy concepts to a natural phenomenon and use the equation E = mc2 to make a related calculation. [SP 2.2, 7.2]

LO 5.C.1.1: The student is able to analyze electric charge conservation for nuclear and elementary particle reactions and make predictions related to such reactions based upon conservation of charge. [SP 6.4, 7.2]

LO 5.D.1.6: The student is able to make predictions of the dynamical properties of a system undergoing a collision by application of the principle of linear momentum conservation and the principle of the conservation of energy in situations in which an elastic collision may also be assumed. [SP 6.4]

LO 5.D.1.7: The student is able to classify a given collision situation as elastic or inelastic, justify the selection of conservation of linear momentum and restoration of kinetic energy as the appropriate principles for analyzing an elastic collision, solve for missing variables, and calculate their values. [SP 2.1, 2.2]

LO 5.D.2.5: The student is able to classify a given collision situation as elastic or inelastic, justify the selection of conservation of linear momentum as the appropriate solution method for an inelastic collision, recognize that there is a common final velocity for the colliding objects in the totally inelastic case, solve for missing variables, and calculate their values. [SP 2.1, 2.2]

LO 5.D.2.6: The student is able to apply the conservation of linear momentum to a closed system of objects involved in an inelastic collision to predict the change in kinetic energy. [SP 6.4, 7.2]
LO 5.D.3.2: The student is able to make predictions about the velocity of the center of mass for interactions within a defined one-dimensional system. [SP 6.4]
LO 5.D.3.3: The student is able to make predictions about the velocity of the center of mass for interactions within a defined two-dimensional system. [SP 6.4]
LO 5.G.1.1: The student is able to apply conservation of nucleon number and conservation of electric charge to make predictions about nuclear reactions and decays such as fission, fusion, alpha decay, beta decay, or gamma decay. [SP 6.4]
LO 6.F.3.1: The student is able to support the photon model of radiant energy with evidence provided by the photoelectric effect. [SP 6.4]
LO 6.F.4.1: The student is able to select a model of radiant energy that is appropriate to the spatial or temporal scale of an interaction with matter. [SP 6.4, 7.1]
LO 6.G.1.1: The student is able to make predictions about using the scale of the problem to determine at what regimes a particle or wave model is more appropriate. [SP 6.4, 7.1]
LO 6.G.2.1: The student is able to articulate the evidence supporting the claim that a wave model of matter is appropriate to explain the diffraction of matter interacting with a crystal, given conditions where a particle of matter has momentum corresponding to a de Broglie wavelength smaller than the separation between adjacent atoms in the crystal. [SP 6.1]
LO 6.G.2.2: The student is able to predict the dependence of major features of a diffraction pattern (e.g., spacing between interference maxima), based upon the particle speed and de Broglie wavelength of electrons in an electron beam interacting with a crystal. (de Broglie wavelength need not be given, so students may need to obtain it.) [SP 6.4]
LO 7.C.1.1: The student is able to use a graphical wave function representation of a particle to predict qualitatively the probability of finding a particle in a specific spatial region. [SP 1.4]
LO 7.C.2.1: The student is able to use a standing wave model in which an electron orbit circumference is an integer multiple of the de Broglie wavelength to give a qualitative explanation that accounts for the existence of specific allowed energy states of an electron in an atom. [SP 1.4]
LO 7.C.3.1: The student is able to predict the number of radioactive nuclei remaining in a sample after a certain period of time, and also predict the missing species (alpha, beta, gamma) in a radioactive decay. [SP 6.4]
LO 7.C.4.1: The student is able to construct or interpret representations of transitions between atomic energy states involving the emission and absorption of photons. [SP 1.1, 1.2]